BALANCED TO UNBALANCED transformers

There is much more to the humble balun than first meets the eye. Ian White, G3SEK, explains the ins and outs

Real-life antennas are nothing like the textbook pictures. The textbooks show us a simple dipole, fed in the centre, with electric field lines neatly connecting the opposite halves, and lines of magnetic flux looping around the wires. **Fig 1a** is a typical version of this pretty picture, showing only the electric field lines for clarity. Everything is symmetrical, and the system is said to be 'balanced' with respect to ground.

The reality of a typical installation is very different. As **Fig 1b** shows, the electric field lines connect not only with the opposite half of the dipole, but also with the feedline, the ground, and any other objects nearby. The magnetic field may be less disturbed, but the overall picture is in no way symmetrical! Although the electromagnetic coupling between the opposite halves of a horizontal dipole makes the antenna 'want' to be balanced, the coupling has to compete with the distorting effects of the asymmetrical surroundings. As a result, practical antennas can be very susceptible to the way they are installed, and are hardly ever well-balanced.

Contrast the messy environment of the antenna with the tidy situation inside a coaxial cable (**Fig 2**). The currents on the centre core (I1) and the inside of the shield (I2) are equal and opposite, ie 180° out of phase. The two conductors are closely coupled along their entire length, so the equal and antiphase current relationship is strongly enforced. Also, what goes on inside the cable is totally independent of the situation outside. Thanks to the skin effect, which causes HF currents to flow only close to the surfaces of conductors, the inner and outer surfaces of the coaxial shield behave as two entirely independent conductors. You can hang the cable in the air, tape it to a tower or even bury it, yet the voltages and currents inside the cable remain exactly the same. About the only things you can do wrong with coax cable are to let water inside, or bend it so sharply that it kinks. That's why coax is popular - it is so easy to use.

The problems arise when you connect a coaxial cable to an antenna. If the antenna is in any way unbalanced — which it will be, in any practical situation — a difference will appear between the currents flowing in the antenna at either side of the feedpoint. This difference current is shown in **Fig 3** as I3, and is equal to (I1-I2). The current I3 has to flow somewhere. It cannot flow down the inside of the cable because I1 and I2 must be equal; so instead it flows down the outside of the outer sheath. As a result, the feedline becomes part of the radiating antenna. This causes distortion of the radiation pattern, RF currents on metal masts and Yagi booms, and problems with 'RF in the shack'. Even worse can be RF currents flowing in the mains and on TV cables, leading to all manner of EMC problems.

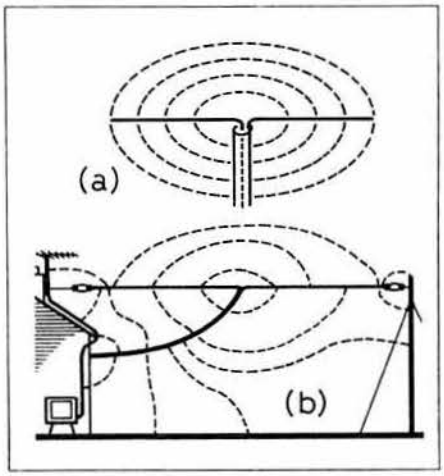

Fig 1. (a) Idealized picture of electric field lines around a coaxial-fed dipole. (b) the typical reality.

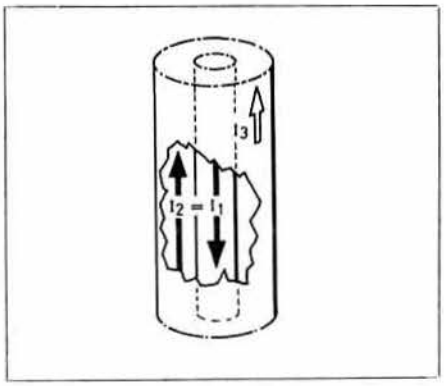

Fig 2. Currents on the inside of a coaxial cable (I1 and I2) are always equal and in antiphase. The skin effect allows a separate current I3 to flow on the outside.

By using an appropriate type of balun at the antenna feedpoint, you can effectively prevent stray surface currents on the feedline. As a result, the current distribution on the antenna will adjust itself to become more symmetrical, so the antenna will work better and many of your EMC problems may also disappear.

BALUNS

The word balun is short for '**bal**anced to **un**balanced'. A balun is a device which somehow connects a balanced load to an unbalanced coaxial line. There are two ways of approaching this task, so there are two distinct types of balun. The **choke balun** aims to prevent I3 from flowing, by placing a large series impedance on the outside of the feedline. As a result, the antenna currents can only flow on the inside of the feedline, and the properties of the coaxial cable force the antenna currents at either side of the feedpoint to be equal and in antiphase, ie balanced. The **transformer balun** aims to force the voltages and currents at either side of the feedpoint to be equal and in antiphase. As a result, no difference current I3 remains to flow down the outside of the feedline.

Antenna balance and feedline surface currents are inter-related, and choke and transformer baluns are merely tackling the same problem from its two opposite ends. Choke off the difference current, and the antenna currents must adjust themselves to become more symmetrical. Alternatively, try to make the antenna currents equal, and the difference current will tend to disappear. Given these opposite approaches to the same problem, you can see how a variety of quite different-looking devices come to be called 'baluns'. And since the same kind of balun can work well in one situation but not in another, it's small wonder that many people find the subject confusing.

Further confusion arises because baluns can be used for different purposes. To give just two examples, a balun can be used to cure TVI by suppressing feedline radiation; or it can be used to force a more symmetrical current distribution upon an antenna which is basically unbalanced with respect to ground (eg a low-mounted vertical dipole). In these two examples you are expecting quite different things from the balun, so you might well choose a different type for either task.

To clarify matters, let's look at some well-known baluns and see how they work - and when they might not.

CHOKE BALUNS

The simplest baluns are the ones that prevent surface currents from flowing, by forming the coaxial cable into an RF choke at the antenna feedpoint. (The currents flowing inside the cable are quite unaware that the cable has been coiled up.) At its very simplest, a choke balun can be just a few turns of cable in a loop of diameter six inches to a foot (**Fig 4a**), and in some circumstances this may be all you need. Alternatives are to wind the cable around a toroid or a ferrite rod (**Figs 4b and 4c**). Yet another alternative popularized by W2DU is to feed the cable through ferrite tubes or beads to form a sleeve (**Fig 4d**); this is generally lighter and more compact than a coiled choke, but somewhat more expensive. Ideally the cable should be a close fit inside the ferrite sleeve, and this may not be easy to achieve with readily available materials.

The VHF or UHF equivalent of the choke balun is the quarter-wave sleeve or 'bazooka' (**Fig 4e**). The sleeve forms an additional section of coaxial line over the outside of the cable, and this outer

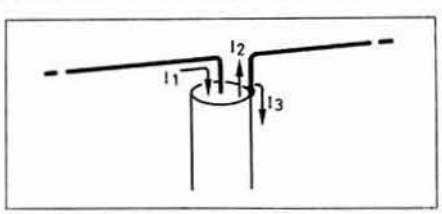

Fig 3. If the antenna currents on either side of the feedpoint are unequal, the difference I3 = I1 - I2 will flow down the outside of the cable.

line is short-circuited a quarter-wavelength away from the feedpoint. At the feedpoint, a quarter-wave distant, this short-circuit appears as a high impedance against currents flowing onto the outer surface of the coax. At its resonant frequency, the bazooka thus acts as an RF choke on the outer surface of the feeder.

The power rating of any choke balun is essentially that of the cable itself. Even if magnetic material is involved, the main feeder currents cancel inside the cable, leaving only the small residual surface current to magnetize the core.

Although choke baluns will prevent surface currents from flowing at the feedpoint itself, electromagnetic coupling between the antenna and points further down the feedline may induce surface currents which the balun cannot prevent. This will happen if the installation is asymmetrical.

Induced currents become much greater if the feedline length is resonant, producing greater RF voltages on the line and on the equipment in the shack. The resonant length has to be measured from the feedpoint, down the coaxial cable, through the equipment in the shack, and away to down to RF ground via various lengths and loops of wire and metal plumbing. There can be many additional loading effects which alter the resonant length from its free-space value, so it can be very difficult to identify the exact causes of feedline resonance. This can lead to mysterious complaints such as 'Ever since I put in this new coax, I've had RF in the shack! Should I send the cable back?'

So if a choke-type balun fails to suppress feedline currents, the solution is to *leave the balun there*, but also place further RF chokes (Figs 4a, b and c) at intervals down the feedline to interrupt any resonant current distributions. A suitable interval would be a quarter-wavelength, or in a multiband system you could use pairs of chokes 2.5-3m apart, avoiding half-wave separations at any frequency in use.

TRANSFORMER BALUNS

A balanced antenna feedpoint will present an equal impedance from each side to ground. The accusation levelled at choke baluns is that they treat the symptom (the surface current I3) without attempting to correct the imbalance that causes it. A transformer balun, on the other hand, does create equal and opposite RF voltages at its output terminals, relative to the grounded side of its input. This works fine in the laboratory; but up in the air where the balun is located, what exactly do we mean by 'grounded'?

Transformer baluns may or may not involve a deliberate impedance transformation. We are probably all familiar with the basic 1:1 and 4:1 baluns; **Fig 5** shows a wire-wound 1:1 balun, and both wire-wound and coaxial-cable versions of the 4:1 type. These all have the common property of forcing balance at their output terminals by means of closely-coupled windings within the transformer itself. The 4:1 balun in **Fig 5b** is the easiest to understand. Typically, it transforms 50Ω unbalanced to 4×50=200Ω balanced. This is achieved simply by a phase inversion. An applied voltage v at one side of the feedpoint is converted by the transformer action into a voltage $-v$ at the other side. These two voltages 180° out of phase represent the balance we are seeking to achieve. The 4:1 impedance transformation arises as follows. If the original voltage on the feedline was v, the voltage difference between opposite sides of the feedpoint is now $2v$. Since impedance is proportional to voltage squared, and $(2v)^2 = 4v^2$ the impedance is stepped up by a factor of 4.

In the wire-wound 4:1 balun (**Fig 5b**), the 180° phase inversion is achieved by the connection of the windings, while the coaxial equivalent (**Fig 5c**) does it by introducing an electrical half-wavelength of cable between opposite sides of the feedpoint. Strong coupling between the windings or inside the coax forces the whole system into balance.

Or does it? If you treat any balun as a 'black box' and look at the currents flowing in and out, you will find that any current difference between the two sides of the antenna has nowhere else to flow but down the outside of the coax [1]. But that does not mean that the balun is no better than a direct connection; when you insert the balun, it forces the currents in the antenna to readjust themselves to become more symmetrical. To make a meaningful evaluation of the effects of a balun, you therefore need to include the entire antenna and its surroundings in your analysis.

Any unbalanced antenna/feedline system will always 'push back' against an attempt to force it into symmetry. So although the transformer balun may do a good job, it still may not achieve total equality between the currents on opposite sides of the feedpoint. That may leave a residual difference current I3 to flow down the outside of the coax, as noted above. Unfortunately, having made its effort to minimize that difference current, the transformer balun does nothing to prevent it from flowing onto the coax. And there is still the possibility of additional currents being induced further down the surface of the feedline. This implies that a transformer-type balun may require additional RF chokes, at the balun itself and possibly further back down the line.

PROBLEMS WITH BALUNS

Some people swear by baluns, while others swear *at* them because they allegedly cause mismatches, get hot, generate harmonics and spread despondency. Many of these problems are not the fault of the balun itself.

A 'pure' choke balun acts only on the outside of the feedline, and cannot introduce any impedance mismatch on the inside. However, introducing an innocent choke balun can in fact change the VSWR. You may even find that the VSWR changes when you insert an extra length of coax, which is totally contrary to the theory of standing waves! The VSWR measured anywhere along the feedline should always be the same, says the theory - but only if the load impedance hasn't changed. And that is the clue to the puzzle. Recall that if the system is unbalanced, the outside of the coax becomes part of the antenna itself. So when you change the feeder length, you are in fact altering the whole antenna system and changing the distribution of RF currents upon it. The change in currents at the feedpoint will indeed change the load impedance, so that changes the VSWR.

Yet another complication is that some VSWR meters are not RF-tight, and permit a crossover of currents between the inside and outside of the coaxial line. Such meters will react to changes in out-surface currents, with a constant VSWR.

The sensitivity of the VSWR to the length of feedline can be a very good test of the effectiveness of a balun in your particular situation. Simply add an extra quarter-wave of feedline, using well-matched coaxial connectors, and see if the VSWR varies. The variations with a balun in place should be markedly less than without one.

We can now deal with another well-worn question. Can you avoid the need for a balun by

In Figs 4-11, U = unbalanced, B = balanced. The impedence is typically 50Ω unless noted otherwise.

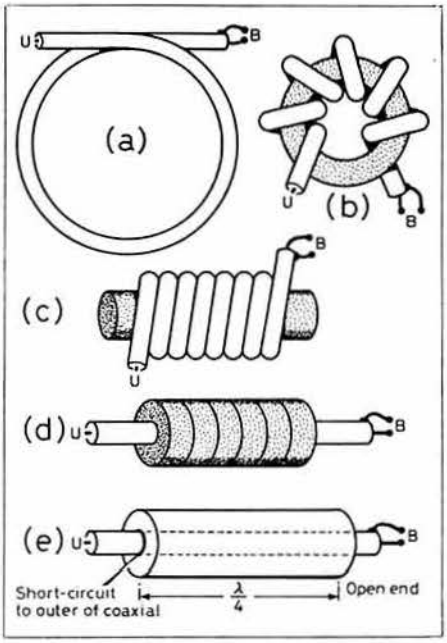

Fig 4. Five varieties of choke-type balun. (a) Coil of coxial cable (typically 6-10 turns — only one turn shown). (b) Coaxial cable on toroid. (c) Coaxial cable on ferrite rod. (d) Ferrite sleeve. (e) Quarter-wave sleeve or 'bazooka'.

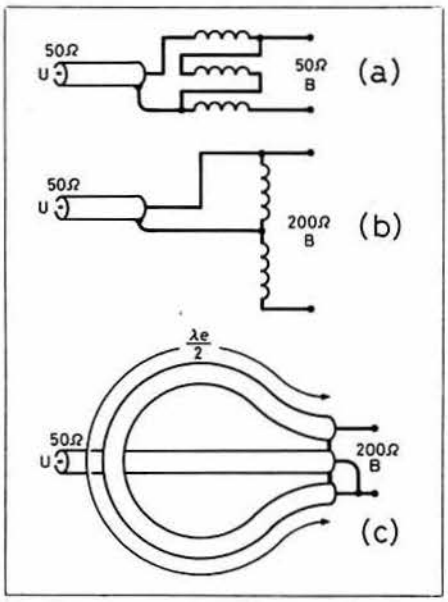

Fig 5. Transformer-type baluns. Windings shown separately are bifilar or trifilar wound, possibly on a ferrite rod or core. (a) Wire-round 1:1 (trifilar). (b) Wire-wound 4:1 (bifilar). (c) Coaxial 4:1. The half-wavelength includes an allowance for the velocity factor of the cable.

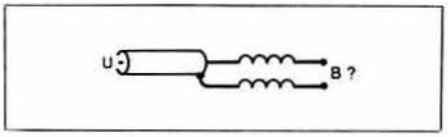

Fig 6. A bifilar 1:1 balun is rather ineffective.

providing a perfect resonant match? The answer is 'NO'. Impedance matching, as measured by the VSWR, occurs entirely inside the coaxial cable, whereas antenna balance and feedline radiation happen in the world outside. So VSWR and balance are totally separate issues unless they interact at the antenna feedpoint, the only place where the inside and outside are joined. To stop that interaction, you always need a balun.

Having sorted out those misconceptions about impedance mismatches which are not really the fault of the balun, what about the genuine mismatch problems caused by the balun itself? Many papers and articles have been written about this, and especially about wire-wound transformer baluns [2-6]. The fact most overlooked by amateur constructors is that the windings of the balun form an extra section of transmission line between the coaxial cable and the antenna. In order to match 50Ω cable to a balanced 50Ω load, the transformer windings must themselves be 50Ω lines. Now it so happens that two pieces of enamelled wire twisted together, or laid close and parallel, will make a transmission line with a characteristic impedance of about 50Ω — but not exactly, so some impedance mismatch can arise. Distributed capacitance between the turns of the transformer can cause unwanted resonances which create impedance mismatches and throw off the balance, and so too can the leakage inductance due to carelessly loose coupling between windings.

We can examine these problems further by looking at a few practical types of balun.

PRACTICAL HF TRANSFORMER BALUNS

First, let's look at one which is hardly a balun at all. This is the type of 1:1 wire-wound balun shown in **Fig 6**, which is simply a length of 50Ω twin-wire line wound into a bifilar choke. If a load which is already well balanced needs to be connected to an unbalanced source, this type of balun will let it happen; but it won't contribute much positive help. Since the impedance of the twin-wire line is unlikely to be exactly 50Ω, you would probably do better with a fully coaxial choke balun.

The performance of the 1:1 balun is improved dramatically by adding a third winding (**Fig 5a**) This provides a necessary current path from end to end of the choke, without upsetting the desired voltage and phase relationships. The third (tertiary) winding must have close magnetic coupling with the other two. This is usually achieved by winding all three wires together, either laid parallel or twisted, in a trifilar winding. G6XN gives some good advice about techniques for wire-wound baluns [5]. Instead of twisting the wires, you could wrap three straight wires together with plumber's PTFE tape as suggested by GM4GSJ, and then wind all three onto the former or core; the tape makes the wires lay down flat and parallel.

A successful alternative to the three-wire 1:1 balun is to keep the two main wires coaxial, and lay the tertiary winding close alongside as shown in **Fig 7** [2]. This has the advantage of avoiding impedance discontinuities in the main line. The constructional technique suggested in the original article was to strip the outer insulation from thin coax, and to bind the enamelled tertiary wire closely to the coax using heat-shrink sleeving. PTFE tape would work equally well, but would require additional waterproofing. The fact that one wire is inside a coaxial cable, one is outside and the third 'wire' is tubular has no effect on the magnetic coupling between all three. This type of

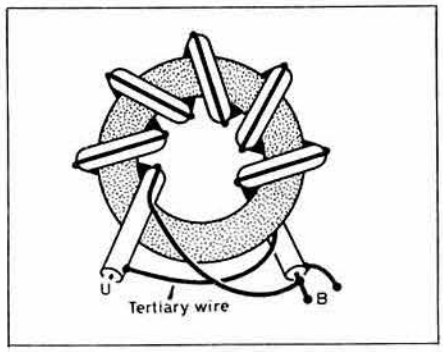

Fig 7. Toroidal trifilar balun using coaxial cable plus a tertiary wire

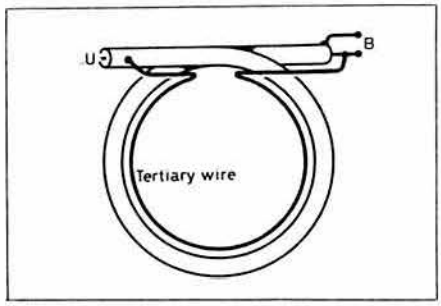

Fig 8. The coaxial choke balun of Fig 4a can be improved by adding a tertiary wire. For 14-30MHz, make a two-turn coil using 600mm of cable and the same length of wire, plus small additional lengths for connections.

construction is reported to give excellent performance with a particularly good impedance match.

The simple choke balun of fig 4a can be improved in a similar way by adding an extra tertiary wire to the coil of coax. This converts the choke balun into an air-cored version of Fig 7 [6], which should be suitable for the 14-30MHz range. **Fig 8** shows the construction; as with the toroidal version, the coaxial cable and tertiary wire must be bound very closely together, with short connections where the tertiary wire crosses over.

BROADBANDING AND MAGNETIC CORES

Most types of HF balun are designed for good broadband performance, typically for use with 3.5-30MHz multiband dipoles or 14-30MHz beams. The limits on performance are usually expressed in terms of accuracy of amplitude balance from

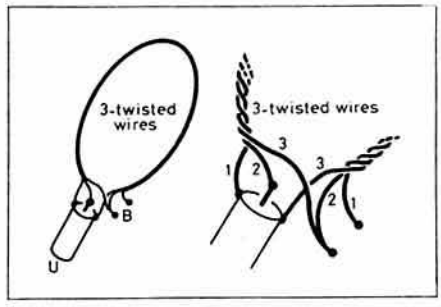

Fig 9. Air-cored trifilar 1:1 balun for 14-70MHz by G3KJC. The 50Ω trifilar transmission line is made from three lengths of 1·6mm enammelled copper wire. Holding one end of the bundle in a vice and the other end in a hand-drill, stretch the wires straight and parallel and then make 20 regularly spaced twists along a 500mm length. Coil the wires up 2 turns and make short cross connections as shown.

side to side, accuracy of phase angle, and VSWR. Balance within 1dB, a phase angle of 180±10° and a VSWR of less than 1.5 into a balanced load are generally regarded as adequate performance at the edges of the operating band. In fact all of these characteristics tend to be related.

The high frequency limit of performance is approached when the distributed capacitance of the transmission line becomes series resonant with its leakage inductance [5]. At the series-resonant frequency, somewhere around 50-100MHz for typical HF construction, the balun becomes completely useless, and in practice it should not be used above half that frequency [2]. The lower frequency limit on performance is set by the requirement that the reactance of the inductive winding must be several times the circuit impedance. If we require the reactance to be eight to ten times 50Ω at 3.5MHz, the inductance of the winding should be 20-25μH. Since a large number of turns would spoil the HF response, a magnetic core is generally used to extend the broadband performance on the LF side.

Conventional toroidal baluns are generally made with either 10-12 trifilar turns on a 'number 2' iron-dust core of permeability 10, about 6 turns on a nickel-zinc ferrite core (μ = 120), or 3-4 turns on a high permeability ferrite core. With proper construction, all of these baluns can have excellent performance down through 3.5MHz, and may still be going strong at 1.8MHz. However, their performance at 28MHz may deteriorate if either the leakage inductance or the electrical length of poorly matched twisted-wire line are becoming significant; these are potentially more serious problems for the baluns which use greater numbers of turns on a lower permeability core.

G6XN has pointed out that it is not necessary to use a toroid; six or seven trifilar turns on a medium-wave broadcast type of ferrite rod will work perfectly well, and at far less cost [5]. Such a balun has rather less series inductance than the normal toroidal balun, so it shifts the whole performance band upwards in frequency. The performance of G6XN's type of balun is excellent, especially on the higher HF bands. I have built several using six trifilar turns on pieces of scrap ferrite rod. Although originally intended for 14-30MHz, with careful construction they are usable at 50MHz upwards, and cost next to nothing.

Poorly matched loads can ruin the performance of a balun, particularly at the HF end of its range where the length of the coiled transmission line may approach an electrical quarter-wave. The resulting high VSWR and increased circulating currents can cause saturation of high-permeability ferrites. This in turn can lead to overheating, and either temporary or permanent loss of magnetic properties. The solution is to avoid mismatches in the first place — which implies that the output side of an ATU is often not a good place for a balun with a magnetic core — and also to use larger sections of magnetic materials which are less prone to saturation. A balun wound on a straight ferrite rod is much less prone to saturation than a toroid, because most of its magnetic circuit is 'air gap' rather than ferrite.

The high-frequency balun designed by Roy Church, G3KJC, uses no magnetic core at all. The balun shown in **Fig 9** works from 14MHz to at least 70MHz and is wound on fresh air! A coil of trifilar twisted wire provides plenty of series inductance for these frequencies. The secrets lie in getting the right number of twists per inch to make a good 50Ω transmission line, coiling up the wire to create

the necessary series inductance, and making short VHF-type connections between the various windings. It is virtually impossible to overload or damage this balun by either raw power or high VSWR. Having no core, there is nothing to saturate, and the voltage breakdown is limited only by the quality of the enamel - the prototype survived 3kV DC between adjacent wires! As with any balun, it should be mounted reasonably far from metal objects, particularly those made of magnetic materials.

TESTING HF BALUNS

Low-power tests on HF baluns can be made using a balanced dummy load consisting of two resistors in series. You don't need a professional vector impedance meter or network analyser to tell the difference between a good balun and a poor one. You can measure the VSWR of the balun on all the amateur bands in the normal way. Frequency-swept measurements using a general coverage receiver and a noise bridge can be even more revealing, especially if you can extend them up to about 100MHz, where most HF baluns look extremely sick! By grounding the centre-tap between the two load resistors, you can also measure amplitude balance using a high-impedance RF voltmeter or oscilloscope.

The main high-power test is of insertion loss. Since a high-power balanced dummy load may be difficult to arrange, the best way to carry out this test is to make two identical baluns and connect them back-to-back between the transmitter and a normal coaxial dummy load [5]. With the aid of an RF wattmeter you can estimate the power loss in the pair of baluns, though a simpler test is to feel their temperature after a few minutes carrying full power. The balun might reasonably become warm to the touch; if it gets really hot, it is either under-rated, badly designed or badly constructed.

WHICH HF BALUN IS BEST?

The question of choke versus transformer baluns has generated fervent debate for years (especially among people who believe that every issue can be resolved by confrontation). So don't expect me to end all that in a few paragraphs! The underlying question is whether antenna imbalance should be tackled by eliminating feedline currents, or *vice versa*. Since each follows from the other, like the proverbial chicken and the egg, both answers are equally right - or wrong.

More to the point, W7EL has made some direct comparative tests between choke and transformer baluns in something approximating a real situation. The baluns were inserted between a horizontal 28MHz dipole and a half-wavelength of coaxial feeder [1]. Since the transmitter end of the feeder was well grounded, this feeder length presents a particularly low impedance to surface currents at the feedpoint, and places great demands on the balun. W7EL measured the currents in the dipole at both sides of the feedpoint, and also the imbalance current on the surface of the coax. He found that even minor physical asymmetry in the installation resulted in marked electrical asymmetry; and that both types of baluns produced improvements.

Many amateurs have found this for themselves. Whichever type of balun cures your particular problems (such as RF in the shack or EMC), it's good enough. However, in W7EL's experiments the choke balun produced consistently better improvements in balance than the transformer type. This is consistent with the lack of direct

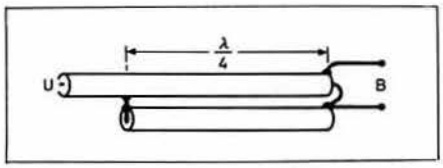

Fig 10. Pawsey stub quarter-wave 1:1 balun.

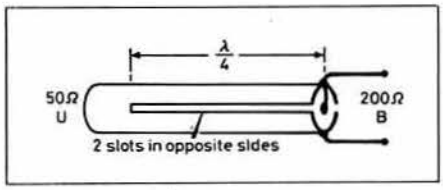

Fig 11. UHF version of the half-wave 4:1 balun.

effort in the transformer balun to suppress feedline surface currents. On the other hand, we hear plenty of stories of choke baluns that failed to work too.

The verdict is that either type of balun at the feedpoint will have a positive effect, but that the 'best HF balun' depends entirely on your particular circumstances and the problem you wish it to cure. Whichever balun you use, you may also need to wind the coax into additional RF chokes to remove the last traces of outer-surface currents.

VHF AND UHF BALUNS

At VHF and UHF there are generally fewer difficulties with imbalance created by the antenna's surroundings. The problem is usually the difficulty of making a symmetrical junction at the feedpoint, because the lengths of connecting wires and the necessary gap at the centre of a dipole become significant fractions of the wavelength.

For all its popularity, the gamma match is not a balun. It does nothing to create balance between the two sides of a dipole; on the contrary, it relies entirely on electromagnetic coupling between the opposite sides of the dipole to correct the imbalance of the gamma match itself. When used with an all-metal Yagi, the direct connection of the coax shield to the centre of the dipole invites the resulting imbalance currents to travel along the boom as well as the outer surface of the feedline. I have used a gamma match successfully at 50 and 70MHz, but personally would not recommend if for 144MHz or above.

The quarter-wavelength 'bazooka' or sleeve balun has already been mentioned as a VHF/UHF example of a choke balun. Although reasonably successful when used with a well-balanced load, it does little to create balance where none already exists. The Pawsey stub 1:1 balun (**Fig 10**) uses direct connections to a quarter-wave stub instead of relying solely on electromagnetic coupling to create a high impedance against surface currents. However, it requires very short connections at the feedpoint and thus is difficult to construct for UHF. Unless provided with a sliding short-circuit bar to achieve exact quarter-wave resonance, the Pawsey stub may introduce phase-shifts and other problems of its own.

The coaxial half-wave balun is definitely the 'best buy' for all VHF/UHF bands up to at least 432MHz. It strongly enforces balance, yet it does not introduce an impedance mismatch unless the cable or its length is markedly different from a true electrical half-wavelength. The problem with using this balun is that the feedpoint impendance of the antenna must be transformed up to 200Ω. Fortunately, this is often very simple. For example, the highly successful family of DL6WU long Yagis [8] have a feedpoint impedance which is close to 50Ω at the centre of the dipole driven element; this impedance can be raised to the necessary 200Ω simply by converting the driven element into a folded dipole. Other alternatives for creating a symmetrical 200Ω feedpoint impedance include the T match and the delta match [5].

The impedance of the coaxial cable used in a half-wave balun is not important, though a characteristic impedance of one-half the load impedance (ie in most cases 100Ω) has been shown to give optimum broadband balance [7]. Low-loss 100Ω coax is difficult to obtain, though, and it is perfectly adequate to use good-quality 50Ω cable, carefully cut to length with an allowance for the velocity factor.

As the frequency increases, constructional techniques can change to take advantage of the decrease in wavelength. Although an accurate half-wave loop of coax can become quite difficult to make at frequencies above 432MHz, it becomes possible to use a different form of construction instead in the 4:1 balun of **Fig 11,** the end of the solid outer shield of the 50Ω coax is slit back a quarter-wavelength on opposite sides, and the 200Ω load is connected across the separated ends of the shield. The inner of the coax is connected to one side. This works as a 4:1 balun because the final quarter-wavelength of cable supports two electromagnetic transmission-line modes. Firstly there is the normal coaxial mode, which is largely unaffected by the slits in the shield. The second mode is a half-wave resonance from one side of the feedpoint to the other, which creates a 180° phase inversion in just the same way as the more obvious half-wave of cable.

SUMMARY

This article has explained how baluns work, from HF to UHF — and how they might not work in certain circumstances. In particular you may need to use additional RF chokes to prevent currents from being induced further along the feedline. I have also tried to resolve some questions about baluns and VSWR which have puzzled a lot of people for many years. Finally, I have mentioned a few less-common ideas for baluns at HF, VHF and UHF; I hope you'll try them for yourself. □

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